

LED (Light Emitting Diode), Working, Uses, Advantages

July 10, 2026 • vajiramandravi.com



LED stands for Light Emitting Diode. It is a **p-n junction semiconductor diode** that emits light when current flows through it. LEDs are highly energy efficient and convert electrical energy into light energy efficiently. It is used in every electronic equipment that is used to display any kind of information. It is used for illuminating streets, homes, and industries.

Energy efficiency and sustainability have become pressing challenges worldwide. Lighting accounts for 15-20% of global electricity consumption. Transitioning to energy-efficient lighting technologies can significantly reduce **electricity usage** and **carbon footprint**. LED, or Light Emitting Diode, lighting has thus gained immense popularity in the last decade driven by its higher efficiency, lower environmental impact, and reduced maintenance costs.

Basic Structure and Working Principle of LED

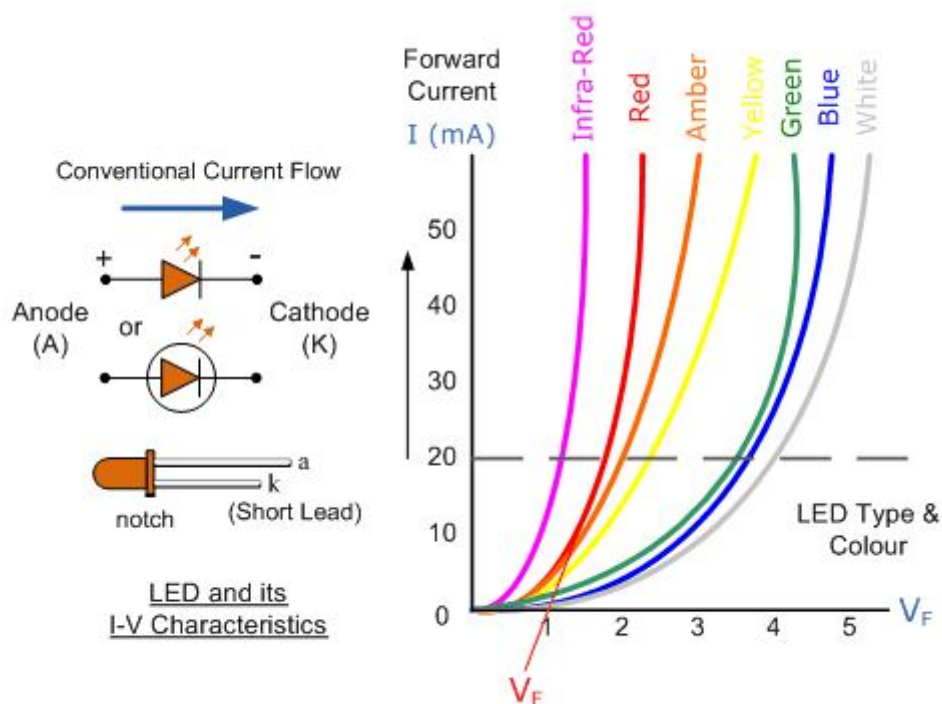
LEDs are PN junction diodes that emit light when operated in **forward bias**. When voltage is applied to the diode in the forward direction, electrons from the **n-type semiconductor** recombine with holes from the **p-type semiconductor** at the junction, releasing energy in the form of photons or light.



- The basic structure of an LED consists of the following components sandwiched together:
 - **p-type semiconductor:** Doped with acceptors to create excess holes. E.g., Gallium arsenide
 - **n-type semiconductor:** Doped with donors to create excess electrons. E.g., Gallium arsenide
 - **Active/Depletion Region:** Where electrons and holes recombine to emit light.
 - **Anode:** P-type layer connected to the positive terminal of the battery.
 - **Cathode:** N-type layer connected to the negative terminal of the battery.
 - **Encapsulation:** Transparent epoxy dome to enhance light extraction.
- **Working Process:**
 - When **forward-biased**, electrons from the **n-region** and holes from the **p-region** are pushed toward the junction. They start recombining in the active region, emitting photons in the process.
 - LED does not emit light when it is **reverse-biased**.
 - The wavelength (colour) of the emitted light depends on the semiconductor material's **bandgap energy**.
 - Different materials like **GaN, GaAsP, GaP**, etc. are used to make LEDs of different colours.

Colour of LED

The emission colour of an LED depends on the **semiconductor material used** and its **bandgap energy**. Different materials, like **GaN, GaP, GaAs**, etc., and their alloys emit different wavelengths from **blue** to **red** by tuning the bandgap. This allows the generating of various coloured LEDs with different forward voltages and optical properties.



Blue LEDs

Blue LEDs emit light in the **blue wavelength range of 450-495 nm**, which falls within the visible light spectrum.

- **Components:** They are made from **gallium nitride (GaN)** semiconductors containing indium or silicon carbide substrates.
- **Features:** They have high energy and a short wavelength, enabling applications like **Blu-Ray devices, data storage, and underwater communications.**
- **Uses:** These LEDs are used to produce white light by coating blue LEDs with a yellow phosphor layer to absorb some blue light and emit a broader spectrum, appearing white.

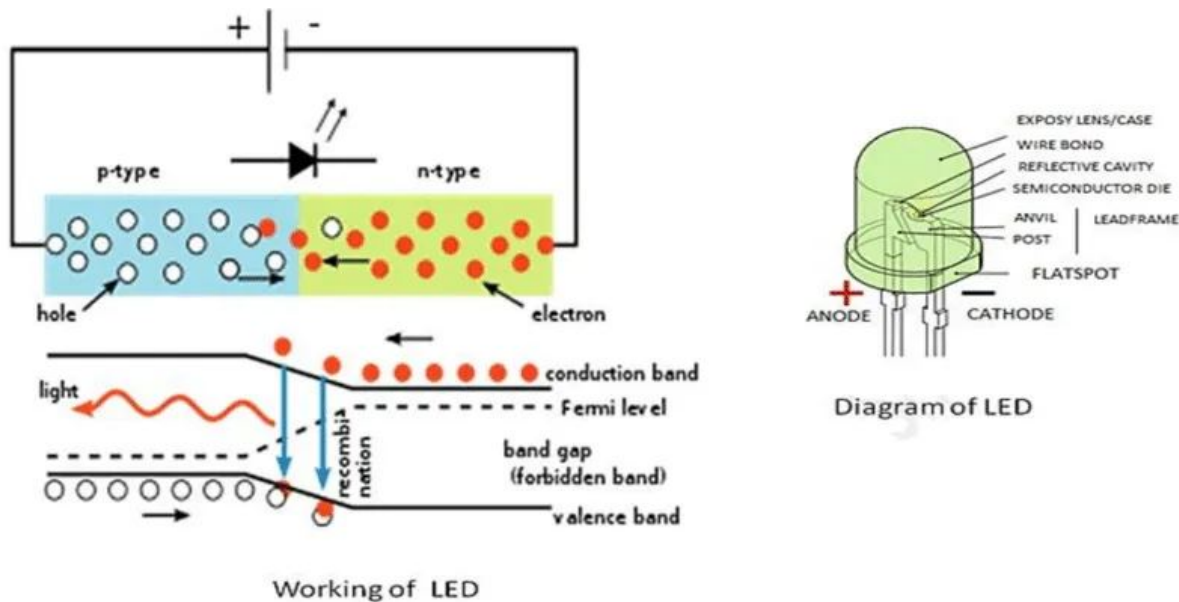
White LEDs

White LEDs emit white light, encompassing the entire visible spectrum from **400-700 nm**.

- **Production:** Two main approaches to generate white light from LEDs:
- **Phosphor conversion: Blue LED + Yellow phosphor coating**
- **Colour-mixed systems:** Combining red, green and blue LEDs (RGB LEDs)
- White LEDs made of blue LED with yellow phosphor coating are the most common as they are simple and inexpensive to produce.
- RGB white LEDs allow colour tuning but are complex and costly.
- **Characteristics:** White LEDs enable **energy-efficient lighting** with high brightness and colour quality which are used in bulbs, street lighting, device backlighting etc.
 - The lifetime and efficiency of white LEDs depend on the phosphor materials used and the quality of the blue LED chip.

Working of LED Displays

LED displays utilise **arrays of light-emitting diodes** to produce a visual output. Key aspects of their working and components are:



- LED pixels made of semiconductor materials emit light when electric current passes through them.
- Each pixel contains a cluster of **red, green and blue** LEDs which in combination can produce other coloured light.
- LED driving circuits selectively switch on LED pixels to generate images and video content by rendering frames.
- As LED pixels are self-emissive, no backlight is required, unlike **LCDs** which enable thinner panels.
- LED pixels can switch on/off rapidly allowing high refresh rates for smooth motion clarity.

Types of LED Displays

There are several types of LED displays based on the technologies and architectures used:

- **Conventional LED Displays:** These displays use discrete LED packages or dies as light sources for each pixel and are available from ultra-low resolution to very high-density configurations.
- **OLED Displays:** These displays use organic light-emitting diode technology where organic thin films form the self-emissive layer between electrodes. They are used in high-end TVs, displays and smartphones.
 - **AMOLED: Active-matrix OLED** displays contain a **thin film transistor (TFT)** array for switching individual pixels separately leading to better refresh rates compared to passive matrix OLEDs which are used in smartphone displays.
 - **SMOLED:** Flexible plastic substrate OLED displays make them bendable and ultra-thin which are used in folding smartphones and wearables.
- **MicroLED Displays:** These displays contain arrays of microscopic-sized LEDs fabricated directly on silicon wafers using lithography which promises next-generation high-resolution displays without bezels.
- **QLED Displays: Quantum dot LED** displays use quantum dot enhancement films along with blue LED backlighting to achieve highly saturated emission colours leading to a wide colour gamut.

- These are used in premium LCD TVs and monitors.
- **MiniLED Displays:** These LEDs use an array of miniscule conventional LEDs for local dimming backlight resulting in better contrast and higher peak brightness compared to traditional LED-LCD panels.

Advantages of LEDs

LEDs offer several benefits compared to traditional lighting solutions:

- **High luminous efficiency:** LEDs convert over 80% of electrical energy into light, compared to 10% for incandescent. This makes them highly energy efficient.
- **Long lifespan:** LEDs can last up to 100,000 hours, reducing the need for frequent replacements.
- **Durable:** LEDs are highly shock and vibration-resistant due to their solid-state nature.
- **Compact:** LEDs are much smaller than bulky incandescent bulbs.
- **Fast switching:** LEDs can be turned on/off rapidly, making them ideal for optical communications.
- **Low voltage operation:** LEDs operate at low voltages typically 1.5-3.5V, making them safe to use.
- **Cool operation:** LEDs emit less heat compared to traditional bulbs removing the need for cooling.
- **Mercury-free:** LEDs are eco-friendly as they do not use toxic materials like mercury.
- **Design flexibility:** LEDs can be made very small and shaped into tiny packages.
- **Controllable brightness:** LED brightness can be varied by changing the supplied current.

Limitations of Light Emitting Diode

Despite the many benefits, LEDs also have some drawbacks:

- **Uni-directional:** LEDs conduct in only one direction (forward-biased) hence, care must be taken during connections.
- **Heat sensitivity:** Excess heat can reduce LED lifetime and efficiency. Proper heat sinking is required.
- **Voltage-sensitive:** LEDs are prone to damage from voltage spikes, so surge protection is essential.
- **High initial cost:** The upfront cost of LED lighting is still more than traditional lighting.
- **Efficiency droop:** Efficiency decreases at high input power densities, limiting light output.
- **Light spectrum:** The emitted spectrum is **narrow** compared to incandescent lights.
- **Light distribution:** LEDs produce directional lighting, and **diffusers** are needed for ambient lighting.

Applications of LED

LED has brought about a paradigm shift in technology with its higher efficiency, reliability, flexibility and eco-friendliness. The most prominent applications include:

- **Indicators and Signalling:** LEDs are used as **Status indicators, Numeric and Alphanumeric displays, Traffic signals, and Sign boards, etc.**
- **Lighting Applications:**
 - In General Lighting, Street Lighting, Automotive Lighting, and Stage/Studio Lighting.
 - In **Healthcare, LED surgical lamps, medical equipment lights, and sterilisation** via ultraviolet wavelengths.

- In **Aviation**, replacing conventional fittings inside **aircraft cabins** for improved lighting and lower maintenance.
- **In Optical Communications:** Visible and infrared LEDs find major use in short-range optical data transmission applications, such as in:
 - **fibre optic cables**, Li-Fi technology, remotes for wireless control signalling, and Optical Mice, etc.
- **Sensing and Detection:** LEDs play a critical role in numerous sensing and measurement applications such as:
 - in barcode and document scanners, movement tracking (with photodiodes and cameras), pattern recognition, in analytical devices, Pulse oximeters and capnographs, Spectrofluorometers, fluorescence sensors (for detection of bacteria, virus, etc.).
- **Displays and Video Screens:** LED technology has revolutionised the display and interface systems with widespread applications.
 - It is used in Mobile phones/smartwatches, LCDs (as a backlighting source), LED TVs, computer monitors, Digital billboards/signage, etc.
- **Other Applications:** Besides lighting and displays, LEDs have many other useful applications including:
 - Machine vision, Phototherapy, Night vision illumination, Currency validation, and Optocouplers.

LED in India

The Government of India has undertaken major policy initiatives and schemes to promote the adoption of energy-efficient and environmentally sustainable LED lighting in the country.

- Some key national programmes driving LED penetration include:
 - **Unnat Jyoti by Affordable LEDs for All (UJALA):** Massive LED bulb distribution scheme implemented by **Energy Efficiency Services Limited (EESL)** that has distributed over **36.78 crore bulbs** across India by 2022.
 - **Street Lighting National Programme (SLNP):** EESL has replaced around 10 million conventional street lights with LEDs across India through this initiative.
- However, **some challenges** need policy interventions to accelerate LED adoption further:
 - **Higher upfront costs:** Despite falling prices, LED bulbs and fixtures remain costlier than conventional lighting like CFLs. This deters cost-sensitive consumers. Subsidies on LED bulb procurement can help.
 - **Voltage fluctuations:** LED drivers are sensitive to voltage spikes and fluctuations in electricity supply. Wider deployment of voltage stabilisers is needed.
 - **Electronic waste:** The lack of LED recycling facilities has led to toxic electronic waste. Establishing e-waste collection and recycling programs is crucial.

LED UPSC PYQs

Question 1: With reference to street lighting, how do sodium lamps differ from LED lamps? (**UPSC Prelims 2021**)

1. Sodium lamps produce light at 360 degrees but it is not so in the case of LED lamps.
2. As street lights, sodium lamps have a longer lifespan than LED lamps.

3. The spectrum of visible light from sodium lamps is almost monochromatic, while LED lamps offer significant colour advantages in street lighting.

Select the correct answer using the code given below.

1. 3 only
2. 2 only
3. 1 and 3 only
4. 1, 2 and 3

Answer: (c)

Question 2: The Nobel Prize in Physics of 2014 was jointly awarded to Akasaki, Amano and Nakamura for the invention of Blue LEDs in the 1990s. How has this invention impacted the everyday life of human beings? **(UPSC Mains 2021)**

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